A simple and complex physical model of the Laurentian Great Lakes used to engage students and community members

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Abstract

The Laurentian Great Lakes, Earth's most-easily recognized feature from space, is of a size, complexity, and significance that can be difficult to comprehend. To address this we have developed corresponding simple and complex physical models to engage students and community members through The University of Waterloo Earth Sciences Museum and the Children's Water Education Council. To clarify and conceptualize the location and size of each of the five lake basins we have provided individual plastic containers for the participants to handle and organize prior to stacking Lego™ underneath their "lake basins" to represent relative elevations. Pipe cleaners or string were then provided to represent length and gradient of the connecting rivers between lake basins. To help the public appreciate the real complexities in shape and size of the Laurentian Great Lakes, the simple, hands-on simulation was then supplemented with a complex multidimensional model produced on a 3-D printer as follows. Great Lakes bathymetric data from the Great Lakes Environmental Research Laboratory of the National Oceanic and Atmospheric Administration were manipulated in QGIS™, 3DEM™, AccuTrans 3D™, and Blender™ programs to create a 3-D Model and then converted to a stereolithography file format to be printed on a fused deposition modeling (FDM) machine. In this presentation we will describe the material and steps involved in creating both the simple and complex physical model to engage students and community members in better understanding and appreciating the largest fresh surface-water system in the world, the Laurentian Great Lakes.

Great Lakes Models

Simple Model: Plastic containers, Lego™ and pipe cleaners were used to show depth, volume, elevation and connections.

3D Printed Model: A model of Lake Ontario was made using a 3D printer and ABS plastic.

CNC Wood Model: A model of Lake Huron's Manitoulin Island was made out of basswood using a computerized routing machine.

	Simple Model	CNC Wood Model	3D Printed Model
Cost	Very low cost. Less than $50 as it uses only cheap common items.	Most expensive model due to the cost of wood. About $500 in basswood and $500 in machining time as well as preparation and finishing costs. Approximately $1500 for a large model with a scale that allows for Lake Superior to be 47'' long (3 times larger than models produced with our 3D Printer).	The cost of 3D printed models is dependent on the volume of material used. The thinner the lake can be made – the cheaper it will be. The models we made were between 4 and 6 millimeters thick, depending on the lake. This gives an overall cost of approximately $1000, for all of the Great Lakes at a printing price of $9 per cubic inch.
Size	Each lake is sized according to available plastic containers.	Largest model, requiring a greater size to be accurate since the accuracy is limited by the size of the router bit. Models made using the CNC machine can be much larger than the 3D printed models as the size limitation is much greater. Our routing machine also has a vertical limit of 4''. This meant the depth of the deepest lake could not be more than 4''. The model can still be made larger, just the vertical exaggeration must be limited.	The size of these models is limited by the size of the 3D Printer which, in our case, was 16'' x 14'' x 16''. The scale factor was determined for the Great Lakes by making Lake Superior 16'' long.
Difficulty	Very simple. Anyone could make it.	Requires a significant amount of file preparation using real data. These files are easier to prepare than they are for 3D printing as the shapes don't need to be thickened. There is more preparation with purchasing and processing materials (wood, glue and finishes).	Most difficult model to prepare. The same meshes used for CNC machining must then be thickened to be made into a shape with volume. This requires advanced manipulation of shapes in Blender™ or another modeling program to thicken the shape properly.
Aesthetics	Not very pleasing but cut outs can be used to show the outline of each lake.	Very pleasing, especially when sanded and finished. The grain of wood can sometimes be deceiving with regard to the depth of the lake. The grain can give a false impression of contour lines.	Not as aesthetically pleasing as wood, but layering of the plastic gives an accurate impression of contour lines.
Practicality	Very practical and easy to transport.	Very heavy and hard to transport. Very durable, but the pinnacles in the deeper lakes are fragile.	Vey light.
Accuracy	Only rough approximations of size, elevation and depth. Little resemblance to actual lake shapes.	The larger it is made, the more accurate it can be. To have the same level as accuracy as the 3D printer (low resolution) it must be at least 3 times as large and have a 10% step over.	Very accurate for its size. Files were also tested with a higher resolution, but contour lines become invisible and in this case the 30% higher cost of higher resolution was not considered justifiable.

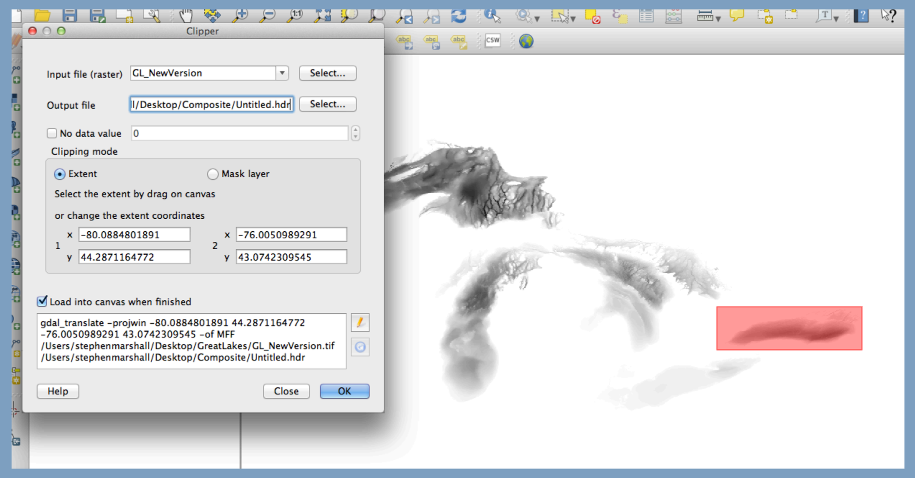
File Preparation

1. Downloading GeoTIFF or ACSII files

Data for geographical areas all over the world are included in these file types. In this case, NOAA (National Oceanic and Atmospheric Administration) was contacted directly in order to get files that contained just bathymetry data and no topography data. This is important because elevation differences in the areas surrounding the Great Lakes are much greater than the depth changes. If the topography data wasn't removed there would have been many more problems associated with creating a model, such as where to cut off each piece, how to fit them together appropriately, and how to avoid distorted topography caused by the vertical exaggeration.

2. Cropping files in QGIS™

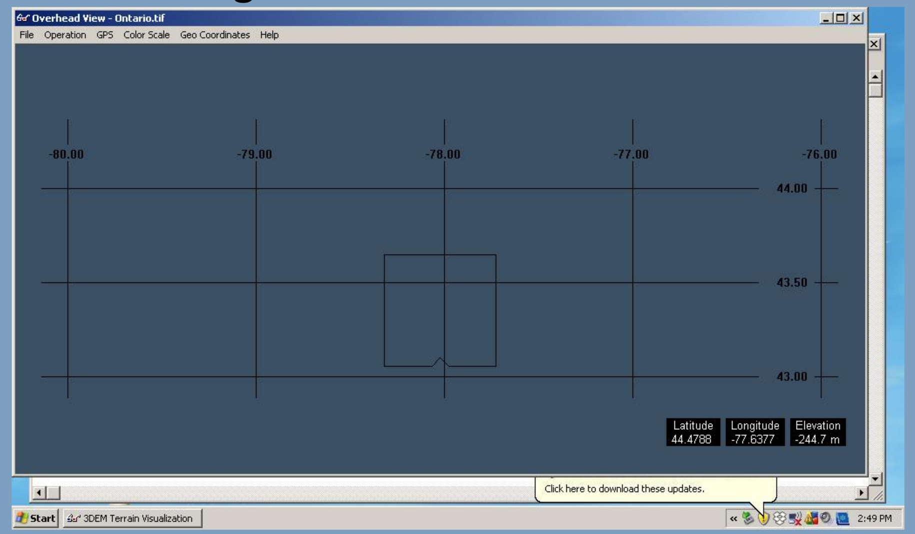
Any GIS program should be able to crop the files. In this case, files were cropped so that each lake could be individually converted into a 3D mesh. This was important because the file requested from NOAA had set each lake to their own datum but had combined all of the lakes into one file. This way all the depths are negative values and everything outside of the lake is a value of 0. If the datum of the file was sea level, Lake Erie would have all positive depth values. If the lakes are cropped like this it is very important to set the 'no-data' value to 0. Export the cropped file as a GeoTIFF.



Lake Ontario being selected using the 'clipper' tool in QGIS™

3. Converting files to DEM format using 3DEM™

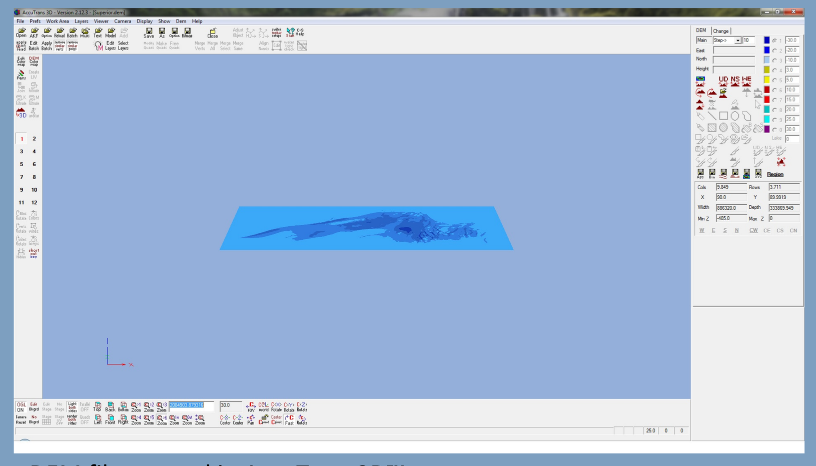
Simply upload the GeoTIFF file and then export it as a DEM file. The lake may not be visible on the screen; this is because the depth change is so minimal that there is no colour change. Scroll the mouse over the lake and the elevation in the bottom right corner should change. This conversion requires a lot of memory and may limit the size of the GeoTIFF that can be converted.



File being converted to DEM in 3DEM

4. Converting DEM files to 3D meshes in AccuTrans 3D™

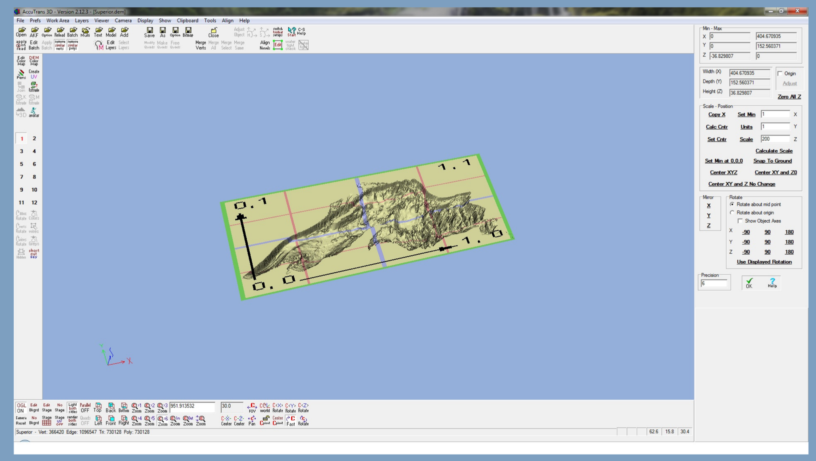
Importing the DEM files into AccuTrans 3D™ will bring up a colour-coded map of each lake. The next step is to use the command "convert to 3D (less water)". This will convert the DEM file to a 3D mesh. It will still look flat since the lakes are very shallow relative to their size. This conversion will give an option to reduce the number of polygons and therefore reduce the resolution. In this case all the data was not necessary as the models are small, so only a fraction of the data points were used. For example, for Lake Superior 1.5 million polygons out of 100 million were used.



DEM file opened in AccuTrans3D™

5. Scaling the meshes in AccuTrans 3D™

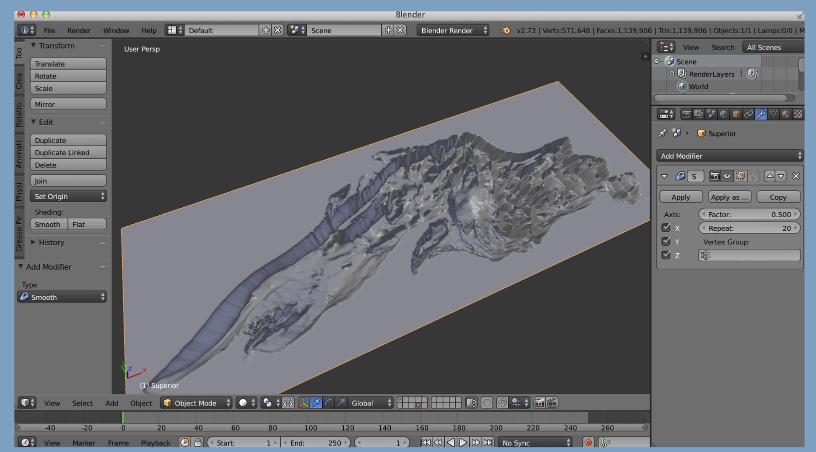
Before the meshes can be imported into Blender™ they must be scaled down to a reasonable size. The scale factor was determined by dividing 405 mm (max size that can be printed by our 3D printer) by the length of the Lake Superior file. The scale factor used for 3D printing was 0.0004569. This scale factor can be adjusted later in Blender™. If the shape is not scaled down before inputting into Blender it will not be visible, as it will be too large. Also, while scaling the shape down, a vertical exaggeration can be applied. In this case, a 200x exaggeration was applied. This will make the bathymetry more visible.



Lake Superior mesh after a 200x vertical exaggeration

6. Smoothing the meshes in Blender™

Due to the vertical exaggeration, the lakes will seem to be very sharp and mountainous. To get rid of this effect a smoothing modifier can be applied. In this case the modifier was applied 20 times. This number was chosen because it was a compromise between having Lake Erie look completely smooth and Lake Superior rendered with too many sharp, breakable, pinnacles.



Applying a smoothing modifier 20 times in Blender™

Final Steps for CNC Machining (wood)

Once the file has been smoothed it can still be scaled in Blender™. It is better to input a smaller shape into Blender™ then scale afterwards, just in case you cannot see it it when you input it, or in case it doesn't render. The test STL files that were machined were scaled up 2.9 times from the files used for the 3D printer.

It is important to determine the appropriate step over for the shape. The step over essentially determines the resolution and detail that the CNC machine can produce. The CNC routing machine used (University of Waterloo, Architecture) has a highest quality using a 10% step over and a quarter inch bit. The lower the step over and the smaller the bit, the higher the quality, but also the longer the cutting time and therefore the higher the cost.

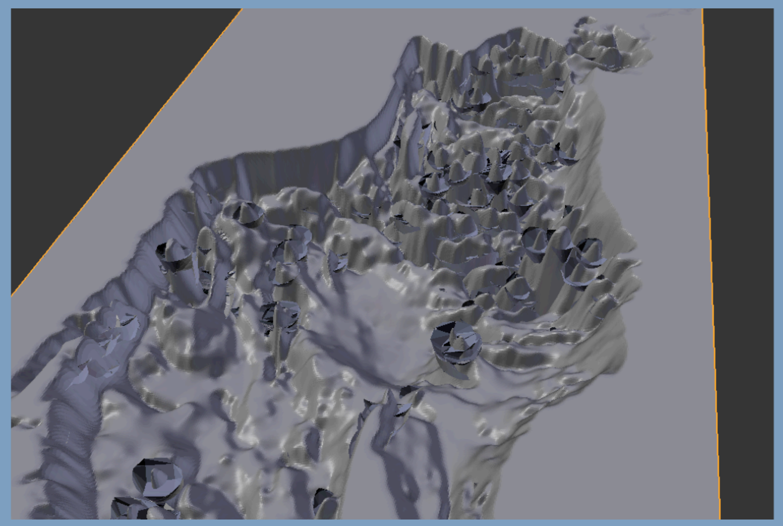
Recommendations

- **A model of the Great Lakes that includes the surrounding topographic data should be made.** It could be made following the same steps outlined above, but would require more computing power as there would be more data points. This model would give the true image of the depths of the lakes with respect to the surrounding topography. It would show how shallow the Great Lakes truly are. This would be better done using a CNC routing machine as it would allow for a larger model.
- **Waterproof 3D printed models that can hold water should be created .** Unfortunately, due to the layered structure of 3D models, they have a tendency to absorb water. To make them watertight would require chemical treatment that would destroy the contour lines that make the model so compelling.
- **Painted models should be produced to better show lake depth.** Painting either the wood or the 3D printed models could allow for better representation of depth. This is especially important in the wooden models, as the wood grain can give the false impression of contour lines.
- **Multilayered wooden models should be made to show contours or stratigraphy.** Preparing a block combining different woods with different layers and colours could allow for a natural contour affect. For example, oak, then maple, then pine etc. These layers could also be bent before being sent to the CNC machine to show stratigraphy.

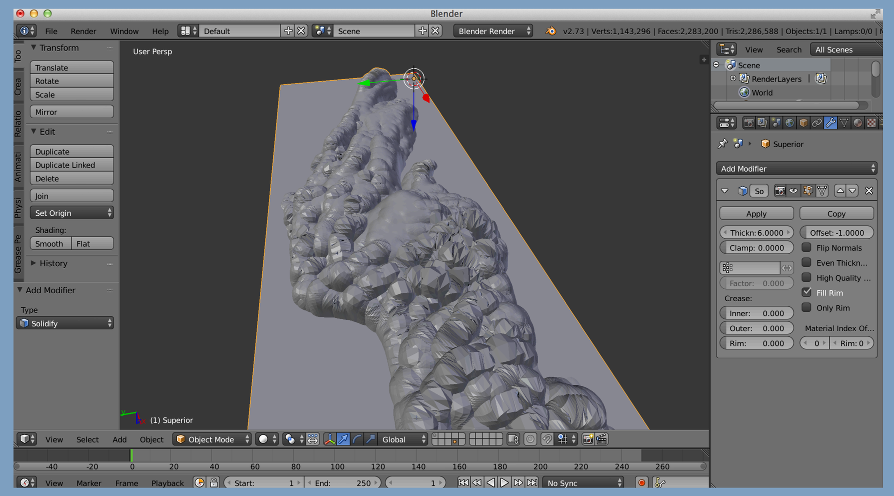
Final Steps for 3D Printer (plastic)

Now that the smoothed meshes have been produced, the next task is to thicken them so they can be 3D printed. This is a very difficult task to do in Blender. There is a function that thickens shapes evenly in Blender™ but it has problems with large complex meshes, as in this case. It often causes protruding geometry out of the top of the lake bottom, due to the sharp pinnacles. It also makes internal geometry that must be removed before the shape can be sent to the printer.

The steps taken to thicken the mesh evenly involved taking a lower resolution identical mesh, thickening it, removing internal geometry and then laying the actual mesh on top of it.



Solidify function causing protruding geometry



Removing Internal Geometry

Microsoft's™ online Model Repair Service was used to remove internal geometry to prepare the lakes for 3D printing.

Note: The file must be exported in STL format to be read by the 3D printer

Note: A properly thickened shape should have a bubbled effect on the thickened side as shown in the picture to the left.

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- Manuel Arab, Department of Earth and Environmental Sciences

References

- National Oceanic and Atmospheric Association (NOAA / GLERL) http://www.ngdc.noaa.gov/mgg/greatlakes/
- Shapespear. (2014, April 25th). Making Miniature Mountains: 3d prints from DEM data https://www.youtube.com/watch?v=bzwybr65l9o

Programs Used:
- QGIS™ http://www2.qgis.org/en/site/
- 3DEM™ http://www.visualizationsoftware.com/3dem
- AccuTrans3D™ http://www.micromouse.ca
- Blender™ http://www.blender.org
- Microsoft™ Model Repair Service https://modelrepair.azurewebsites.net